The
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South Pole of Io

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Cover: A flat plain, probably formed by the repetitive eruption of thin, low-viscosity sulfur, covers the south pole of Io. The dark circular features are calderas formed by such eruptions. The calderas seen in this Voyager image are filled with either liquid sulfur at moderate temperatures or solid, chilled deposits of originally high-temperature sulfur.

PHOTO: UNITED STATES GEOLOGICAL SURVEY, LARRY SODERBLOM

LETTERS TO THE EDITOR

To read about NASA considering abandoning the *Voyager* spacecraft was nothing less than a shock. This is perhaps understandable because eight years ago I was intimately involved in the scientific planning of the mission, and it is with a great sense of pride that I have been following the extraordinary achievements of *Voyager* at Jupiter and Saturn, recounting them in my classes and in public lectures around Europe.

What I now find amazing is the same angry reaction of my students and colleagues here. For them, after launch, *Voyager* had become a messenger of human enterprise rather than just another American gadget. How then can NASA offer it for cancellation when it has become the property of the world?

In these days of global turmoil, the only thing that keeps us going is the hope for the future. The success of missions like *Apollo, Viking* and *Voyager* strengthens our confidence in the human enterprise. America is the country that makes it possible. Shouldn't we keep it that way?

S.I. RASOOL
Chair, Atmospheric Sciences, Fondation de France, Paris
Visiting Professor, IBM Scientific Center, Paris

Having returned from my trip around the world, I like very much to remember my stay at Pasadena during the unforgettable days of the Saturn encounter of *Voyager 2.* I was especially impressed by the numerous activities of many groups and individuals displaying their results at Planetfest '81 at the Pasadena Center! Let us hope that the future of JPL will not be as serious as I read it these days. Let us hope that *Galileo* will continue to exist and to perform its task at Jupiter and let us hope that *Voyager 2* will be successful at Uranus and Neptune. Any foreign observer of those decisions of "budget-cutting euphoria" is shaking his head.

I have been in America. I have seen. The real pioneers with new ideas and undefeatable enthusiasm have not died out. If they had, I should not have made my foot-walk from the Huntington Sheraton to JPL and back on August 26, when the cameras of *Voyager* were still blocked. I hope to be present once more during the Uranus flyby in January 1986 and the Neptune flyby in August, 1989!

FRIEDHELM DORST
West Germany

[*On the day Mr. Dorst walked the several miles from his hotel to JPL and back again, the temperature hovered around 105° Fahrenheit.*—Ed.]

I have enclosed my check for $25.07 which is the proceeds from collecting aluminum cans last month. This brings my can drive collection for the year to $123.77. My friends and I have set our goal for $300.00 for the year. We are sure that The Planetary Society will be successful in the projects undertaken. We shall continue to support you as much as possible.

WILLIAM E. BROOKS
Fairfax, Va.

[*The contributions of Mr. Brooks, and others who have found imaginative ways to support the Society, are being used to fund special Society projects like the "suitcase SETI" of Dr. Paul Horowitz.*—Ed.]

THE END OF THE BEGINNING

An Editorial by Bruce Murray, Planetary Society Vice President

Bruce Murray holds a model of the Mariner 10 spacecraft that mapped Mercury.

Voyager 2 journeyed four years from the warm sands of Florida to the icy environs of Saturn. Scientific specialists have been awed by the intricate and unexpected natural phenomena which characterize the Saturnian system, just as they were earlier bedazzled by Jupiter. Millions of others around the world have been carried along, via instant global communications, on this fantastic journey of the mind.

But a funny thing happened on the way to the outer planets. While the *Voyagers* functioned relatively smoothly in space, circumstances in their terrestrial birthplace were not so harmonious. Double-digit inflation combined with unprecedented levels of interest rates painfully exacerbated the growing disparity between expectations and reality for middle-class Americans. NASA plans for a smooth transition to the reusable space shuttle were dashed by schedule delays and burgeoning costs. All planetary launches following the *Pioneer*/Venus Mission in 1978 became dependent on timely development of the shuttle and upper stages.

Voyager 2 began its ambitious four-planet journey in August, 1977. At that time, *Galileo*, a long-duration Jupiter orbiter also carrying a sophisticated entry probe for direct atmospheric sampling, was firmly scheduled for launch in December, 1982 aboard shuttle flight number 16. Two International Solar Polar (ISPM) spacecraft, one American and one European, were planned to depart by shuttle in February, 1983, on exploratory passages over opposite poles of the Sun. By 1984, the Venus Orbiting Imaging Radar (VOIR) spacecraft was expected to map by radar the permanently cloud-shrouded surface of Earth's closest planetary relative. And even a daring rendezvous with the nucleus of Halley's Comet in 1986 was contemplated.

What is the situation now? *Galileo* is the only remaining U.S. planetary project under development, its Jupiter launch delayed until 1985. The U.S. ISPM spacecraft has been cancelled outright and the launch of its European counterpart delayed until 1986. VOIR, deferred again last year until at least 1988, has come to resemble more the fading grin of a Cheshire cat than a serious national objective. Halley's Comet will be investigated by spacecraft of the Soviet Union, Western Europe, and Japan—but not the United States. By these actions the U.S. unilaterally abandoned world leadership in planetary exploration, one of the 20th century's most uplifting and challenging technological and scientific enterprises. That brilliant burst of American imagination and energy, catalyzed by the *Apollo* decision, carried our senses and intellect inward to Mercury as well as outward beyond Saturn, but now has nearly run its course.

Our new challenge is to maximize the scientific and exploratory significance of the much more modest U.S. deep space activities projected for the 1980's. The Deep Space Net, which so skillfully captured *Voyager*'s faint video signals from a distance of over 1 billion miles, steadily improves. New deep space missions can materialize so long as they don't require increased launch capability nor strain the NASA budget. Opportunities for truly collaborative international deep space efforts may arise to replace the symbolic and sometimes paternalistic arrangements of the past.

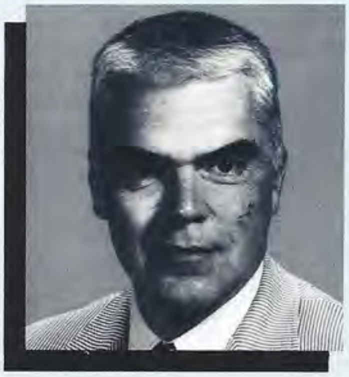
On a longer time scale, ambitious new missions to the Moon and Mars can and should come about in response to the expanding capabilities and aspirations of many more peoples than just those of the U.S. and Soviet Union.

During the next century, humankind's growing comprehension and utilization of our solar neighborhood are likely to make the events of the last two decades seem tiny in magnitude but large in historical import. While foregoing dominance, the United States can still make crucial contributions in a more internationalized era of space exploration. The readership of *Science* [and certainly *The Planetary Report*] can help this uncertain nation to once again look outward in space and forward in time. Perhaps our national expectations of ourselves will once again be rising four years hence, when *Voyager 2* reaches Uranus.

Reprinted from Science, *Vol. 215, No. 4532, 29 January 1981.*

Bruce Murray, Vice President of The Planetary Society, is director of the Jet Propulsion Laboratory.

A TALK WITH HANS MARK



In this issue, The Planetary Report presents an exclusive interview with Dr. Hans Mark, Deputy Director of the National Aeronautics and Space Administration, conducted by The Planetary Society's Executive Director, Dr. Louis Friedman. Comments by the Society's President, Dr. Carl Sagan, follow along with an interview with Dr. Eugene Levy, the retiring Chairman of the Committee on Planetary and Lunar Exploration of the National Research Council's Space Science Board. There are significant signs of a major deterioration in government support for fundamental science, including planetary exploration, as part of many radical changes being initiated by the Reagan administration. The following discussion is intended to aid members of The Planetary Society in evaluating the issues.

Louis Friedman: What goals do you have in space exploration as you and Dr. Beggs take over NASA?

Hans Mark: Our policy for the past decade has been tied to the shuttle and making it work. We've never made any bones about that and it will continue to be our first priority.

LF: What are your long-range goals? What are we doing in space?

HM: There are three things we do in space. We do missions related to the national security, we do commercial missions and we do scientific missions, in that order of priority.

LF: Human exploration and colonization of Mars, manned asteroid landing surveys and a lunar base have been suggested as foci for NASA activity. What is their value and what steps might you suggest for their achievement?

HM: The lunar base is probably the most interesting thing to try. I think the other two are farther downstream and technically more difficult. And, before we do a lunar base, we need to build some permanent facility in Earth orbit. That's the next step. Permanent facilities will come into existence whether we like it or not—the minute we start refueling and refurbishing satellites in orbit, using the shuttle, they become permanent facilities. In a certain sense, the space station will then be here. The lunar base will come later, because we need the space station before we can get people working efficiently in space. But I could be wrong about that.

Perhaps having now spent ten years going to the planets, we ought to return to the Moon. We could begin with a lunar polar orbiter [a NASA proposal rejected several years ago] and do it not only for scientific exploration, but also to look for usable resources. That's not a bad mission.

LF: What about larger space ventures like the manned Mars mission, human colonization of Mars, and asteroid landings?

HM: Right now we're not going to do these things because I don't see the national objective that would drive them. In the case of the Moon, I'm beginning to see a national objective of using the Moon's resources.

LF: Do you think we can wait and be patient for these larger missions, or do you think there is a danger of dissipation and redirection in space science?

HM: I see a couple of scientific missions coming up in the next few years that are of the highest interest, the Space Telescope being the first. We'll see a major breakthrough in astrophysics and we will be able to do things with the telescope that are inconceivable now. I can imagine things coming from use of the Space Telescope that could be fundamental in terms of interactions between high energy physics and astrophysics.

LF: So you don't think there is a crisis in our exploration of the solar system?

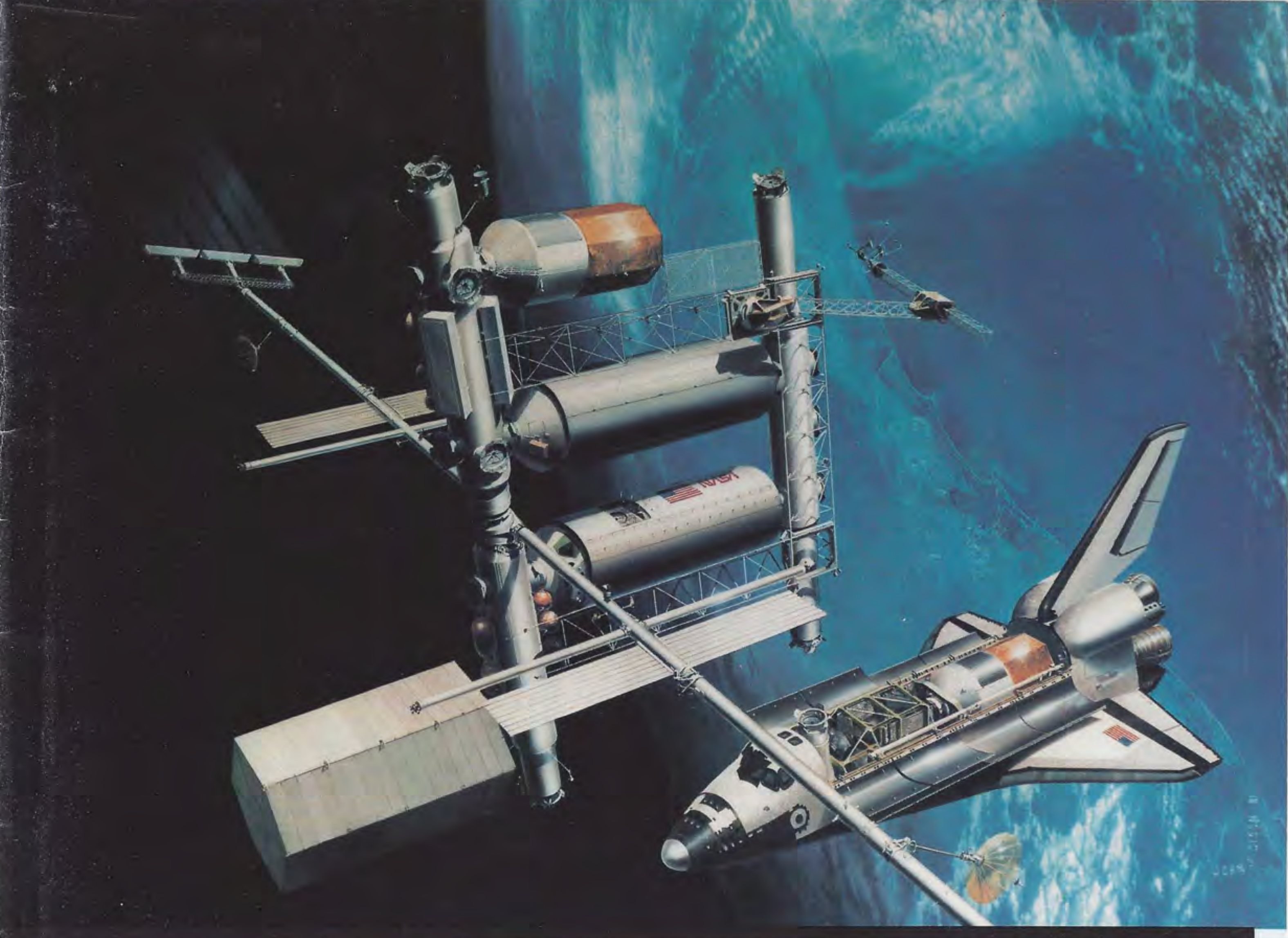
HM: I don't agree that there is a crisis. We've got things on the books, like the Space Telescope, that are exceedingly interesting.

If you're saying "Where do we stand in planetary exploration?", we've done a lot of first-order missions in the last ten years. We are now looking at the second step, which is more difficult because it requires better launch vehicles. There may have to be a hiatus in planetary missions until we can get bigger and better launch vehicles. This hiatus would be quite natural and I don't view it as a crisis. To move on to the next step, we need space stations and the technology to build them in orbit and make them work.

LF: So you think we can afford a lack of continuity in the exploration program?

HM: I don't know that continuity is necessary to scientific enterprise. If you look at the history of science, things go by fits and starts. Let me give you an example. Atomic physics was at the forefront of human knowledge in the 1910's and 1920's. Then, in 1932, Chadwick discovered the neutron and suddenly we had a tool to penetrate the nucleus. People who had done atomic physics went into nuclear physics. For the next few decades, nuclear physics predominated. Meanwhile, people invented things like lasers and methods to accurately control magnetic fields. Then, in the early 1960's, we had a renaissance in atomic physics, and I participated in it. New tools appeared that make problems in atomic physics interesting again.

I think this is going to happen in planetary exploration. Once we get into the next generation of launch vehicles, with the shuttle and upper stages, we're going to find a new level of activity. When I look at something like *Galileo* (the orbiter and probe mission to Jupiter), I ask, "What is conceptually new about it?" We've orbited planets



PAINTING: JACK OLSON, BOEING AEROSPACE COMPANY

and sent probes into them before. Undoubtedly, new things will come from it, but conceptually and historically *Galileo* is in the tradition of past missions. Manned landers, lunar and Martian bases and sample return missions would be conceptually new.

LF: How do you view the reason for and value of the separation between the military and civilian space programs? Do you feel the separation should be maintained, increased or decreased?

HM: The Space Act of 1958 [which created NASA] as a civilian space agency was written in the context of a technology that permitted a fairly clean separation between military and civilian programs. The payload was launched into orbit, owned and operated quite independently of the launch vehicle. Therefore, the fact that we put all our payloads, civilian and military, on launch vehicles that were derivatives of intercontinental ballistic missles (ICBM's) didn't bother anybody.

Now that is changing. With the space shuttle, the interface between the payload and the launch vehicle will be very complicated. As so many times before, this new technology will drive new social arrangements. It may lead to a revision of the Space Act to coordinate flights related to national security with those that are not. Military and civilian projects may go up on the same shuttle flight. Things can happen with the shuttle that weren't foreseen when the Space Act was written in 1958.

LF: Do you think this will be a benefit or a detriment to space science and exploration?

HM: It will be a great benefit. Space science would not exist today if it weren't for the ICBM's. Your whole planetary exploration program is fundamentally dependent on military launch vehicles. This interaction benefits both sides—the national security community and the scientists. I will do everything in my power to encourage that interaction. And I have no fear of being quoted about that.

LF: Many people worry that if military and civilian uses are not separated, the military will always win out in the yearly budget fights and we will see fewer and fewer scientific endeavors.

HM: What actually happens is that, because of the imperatives of the national security, you can hang more and more science on the things that get done. We've done that over and over again. Where do you think high-energy physics would be today without nuclear weapons?

LF: That may be true in certain areas of knowledge, but is it true for beneficial applications?

HM: I don't know what "beneficial" applications are. Historically, the interactions between applications and research have always been unpredictable. The minute you put the word "beneficial" in front, I begin to worry,

(continued on page 23)

A space station (one possible version is shown here) could extend human activities in Earth orbit. Potentially a major NASA objective, the station would be built of modules delivered to low-Earth orbit by the space shuttle.

COMMENTS ON THE CRISIS IN PLANETARY EXPLORATION

by Carl Sagan

One of the objectives of NASA has always been the peaceful exploration of the solar system. In the decades of the 1960's and 1970's, dozens of spacecraft were successfully launched by the United States to the Moon and the planets, performing a preliminary reconnaissance of more than 40 new worlds. At the beginning of the Carter administration's last year in office, there were only three such missions planned for the decade of the 1980's, as shown in the accompanying diagram. In the last year, two of these missions, the U.S. spacecraft for the International Solar Polar Mission and the VOIR mapping mission to Venus, have been cancelled or indefinitely postponed and, as of this writing, only *Galileo* has survived. Even it has been relegated to a much longer, and somewhat riskier, trajectory and flight time to Jupiter.

One major reason for this decline—and in the minds of many scientists, the major reason—is the development of the space shuttle. It is the first reusable launch vehicle. About one-third of its future flights have been reserved for military payloads. As with many major new technological systems, the shuttle cost significantly more than had been originally predicted, has less capability than had been promised, and took longer to become ready for its first operations than had been anticipated. The space shuttle's cost is much larger than the cost of any given planetary mission, and the shuttle cost overruns resulted in a dwindling of resources available for planetary exploration. Furthermore, for the most difficult such missions, the shuttle, with the upper stages it is likely to have in the foreseeable future, is a less effective launch vehicle than the *Titan/Centaur* configuration that launched *Viking* and *Voyager*. This is why *Galileo* will probably have to spend two additional years being first launched into the inner solar system and then accelerated by the Earth's gravity on to Jupiter.

The possibility that the shuttle would have such an adverse effect on planetary exploration was forcefully raised at a meeting of the Division for Planetary Sciences of the American Astronomical Society held in Palo Alto, California in 1974. It was my privilege to chair a panel on the implications of the space shuttle for planetary science. Three of the panel members—James Van Allen of the University of Iowa, Thomas Gold of Cornell University, and Brian O'Leary, then also at Cornell—argued vigorously that development of the shuttle would have grave implications for planetary science. A last panel member demurred, arguing that the space shuttle would imply a healthy NASA with a larger budget, and this would in turn mean more money and more new program starts for planetary sciences. That last panel member was Hans Mark, then Director of NASA's Ames Research Center.

Mark may have been wrong in his prediction but it is noteworthy that he was the only high NASA official invited to discuss this issue who accepted. As the preceding interview shows, Dr. Mark is still willing to take forceful stands on controversial issues. While he was Director at Ames, that Center made major progress in organizing the *Pioneer 10* and *11* explorations of the outer solar system and the *Pioneer* Venus multiprobe mission. He also was a major supporter of the Project Cyclops study, chaired by Bernard M. Oliver, which made detailed recommendations for a thousand-telescope phased array for the systematic search for extraterrestrial civilizations at a cost of many billions of dollars. Mark can by no means be described as an enemy of planetary exploration or the search for extraterrestrial life, although he has repeatedly expressed reservations about the scientific merit of the former. After leaving Ames he became, successively, Undersecretary of the Air Force and Secretary of the Air Force in the Carter administration, then Deputy Administrator of NASA, the number-two post under Dr. James Beggs. Upon assuming his present position, Mark resigned from the Advisory Board of The Planetary Society.

In recent months, Mark has worked tirelessly to prevent the closing of NASA centers, to maintain the Deep Space Network essential for receiving *Voyager 2* data from the Uranus system in 1986, and to preserve the *Galileo* mission. Combined with the work of many others, these objectives seem, at this writing, to have been accomplished. However, at least in the public record, the only arguments considered effective by the Reagan administration involved partisan political advantage and concerns about national security. Arguments on the scientific merits, historical significance and public appeal of planetary exploration (as discussed, for example, in *The Planetary Report,* December, 1979/January, 1980, and January/February, 1982, pages 3 and 11, respectively) were heard but apparently carried no weight. Nevertheless, if slightly more than the present NASA budget is approved by Congress, the minimum conditions for saving the American planetary program may have been satisfied. (Planetary Society members and others who wish to support the planetary program might wish to write the relevant House and Senate Appropriations Committee members whose names are listed on page 21.)

I would now like to take brief issue with some of the points Dr. Mark makes in his interview. While I believe that my opinions are shared by many scientists in the planetary community, I do not claim that they are representative, or even that they constitute some official view of The Planetary Society. These are my personal views:

• Mark implies that the first order exploration of the solar system is essentially complete. It is not. Even excluding the solar system beyond Saturn, we have never visited a comet or an asteroid. We have never seen half of Mercury or, in high resolution, the polar regions of the Moon. We have very incomplete coverage of the satellites of Jupiter and Saturn. There has never been an entry probe that survived more than an hour or so on Venus. We have yet to enter the atmosphere of a major planet (although *Galileo* is intended to do just that). We have not seen, from its surface, any of the most spectacular features on Mars, including the stepped polar terrain, the ancient river valleys, the great volcanos, the chaotic terrain which some scientists believe holds subsurface liquid water, or the enigmatic pyramids of Elysium. We have never entered the clouds or landed on the surface of organic-rich Titan. And we have never returned a sample from any object besides the Moon. All of these missions could be launched with existing launch vehicles.

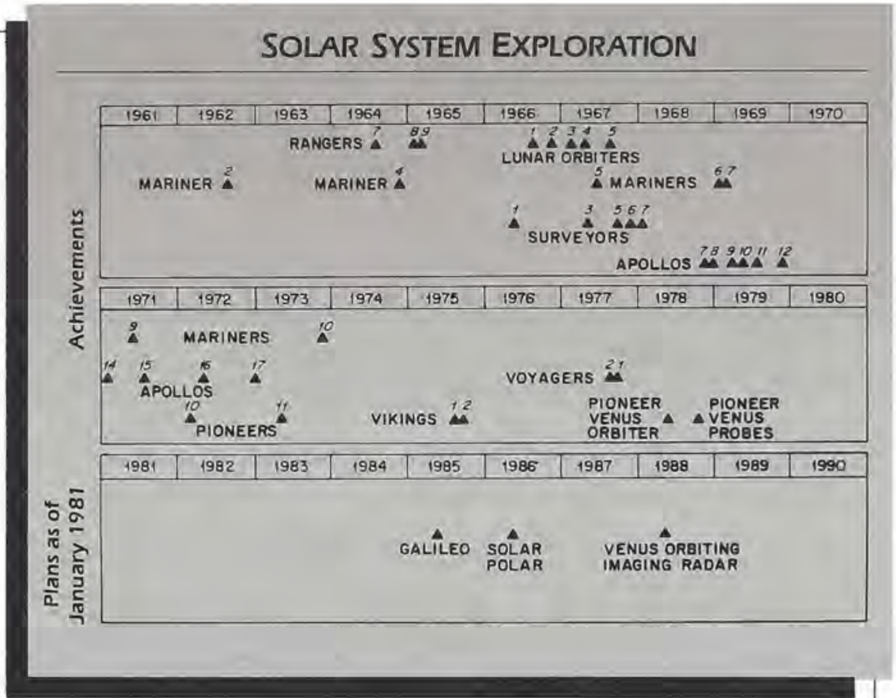
Of course, manned outposts on the Moon or the planets are "conceptually novel." But they are also, in this economic climate, prohibitively expensive and socially unconscionable. Continuation of the extraordinary American initiative of unmanned planetary exploration, established over the last two decades, is comparatively inexpensive, rich in scientific promise, and likely to retain public support.

● The *Galileo* mission, about which Mark expresses some reservations (despite his strong support), promises a multitude of fundamental new findings: on the isotopic composition and organic chemistry of the atmosphere and clouds of Jupiter; as a test of our ability to predict from remote observations the structure and dynamics of a giant planet's atmosphere; on the first detailed examination with a long time baseline of the Jovian magnetosphere—a probable model for the magnetospheres that are central to understanding the physics of pulsars, quasars and other exotic astrophysical objects; on changes over a period of many months in the multicolored markings on the surface of Io, probably produced by volcanos tapping an underground ocean of liquid sulfur; and on the completion of our preliminary mapping of the Galilean satellites where tens of percent of their surfaces have not yet been examined in high resolution.

● Mark argues that there was a period, beginning in the 1930's, when atomic physics moved on to nuclear physics, followed by a resurgence in atomic physics a few decades later. I remind him that the Thomson atom, which attempted to explain the distribution of electric charge inside the atom, was a 19th century invention, and that Rutherford's discovery that atoms have nuclei occurred in 1911. There is a seamless continuity in the histories of atomic and nuclear physics. A nucleus is a part of an atom. Atomic physics might be thought of as a preliminary reconnaissance of the atom, concentrating on the electron cloud, while nuclear physics represents a deeper reconnaissance. The corresponding comparison, it seems to me, is to flyby and orbital investigations of the planets and their satellites as preliminary reconnaissance, and to entry probe, lander and return sample missions as the deeper investigations. We have by no means completed the first set of flyby and orbital studies. But I would be quite happy if NASA were to commit to a long-term program of entry probes, roving vehicles and return sample missions.

● There is a reason that the Act of Congress establishing NASA called for civilian control and separation from military support activities in space. According to Dr. George Kistiakowski, President Eisenhower's last science advisor, the President—a military man almost all his life—insisted on the civilian character of space exploration. The framers of that legislation realized, in their wisdom, some fundamental incompatibility between the scientific exploration of space and military objectives in space. These are quite different goals: the secrecy that is fundamental to military activities is far from fully compatible with the international character, open inquiry, and vigorous self-criticism and debate that characterize the best of science.

● Mark argues that American planetary exploration is the beneficiary of rocket technology developed to carry nuclear weapons to the Soviet Union in ICBMs. This is, of course, true, and in an analogous way it is as true for the Soviet space science program as for the American program. But Mark neglects to mention that the American pioneer in rocket technology was Robert Goddard, whose motivation all his life was to explore the Moon, Mars and beyond. This is perfectly clear from Goddard's personal papers. The same is true for the second major figure in the evolution of American rocket technology, Wernher von Braun. The analogy is again close in the Soviet program, where the corresponding figures are Konstantin Tsiolkovsky and Sergei Korolev. The military rocket technology which can carry weapons of mass destruction (as well as reconnaissance satellites which stabilize global tensions) owes at least as much to the dream of planetary exploration as planetary exploration owes to military technology.



Spacecraft launch times and achievements are listed in the top section, the planned American missions below. The United States' spacecraft for the International Solar Polar Mission and the Venus Orbiting Imaging Radar Mission have been cancelled since this chart was prepared in January, 1981.

● In response to Dr. Friedman's remark that public interest could justify planetary missions, Dr. Mark replies that, "The shuttle was not supported by popular interest." That is certainly true. However, it is not a very pertinent remark. The shuttle is not, by itself, an instrument of scientific exploration. But *Viking* and *Voyager* were supported almost entirely by their scientific and popular interest. The money to support space missions comes from taxpayers, who have in recent years made very clear their interest in and commitment to planetary science.

● Mark talks about "social imperatives" and says that planetary exploration is a comparative luxury. But planetary exploration advances benign high-technology, permits us to compare our planet with others to help us improve the Earth, provides an aperture to a hopeful future, and approaches some of the deepest questions that humans have ever asked—questions of the origins and destinies of worlds, questions on the nature and uniqueness of life. In a time when hope seems in such short supply and when long-term thinking has become a rare commodity, I believe that planetary exploration—especially given its comparatively low cost—is one of the most cost-effective social imperatives around.

Bruce Murray's sober article, "The End of the Beginning" (page 3), reflects the sense that the first phase of American planetary exploration has ended. But the second phase could begin in only a few years—or even earlier—if strong public support is manifested.

The Planetary Society is working to achieve the kind of vigorous planetary program that a prudent regard for the future requires, and looks forward to cooperation with the administration and the Congress.

Carl Sagan is David Duncan Professor of Astronomy and Space Sciences, and Director of the Laboratory for Planetary Studies at Cornell University.

A Talk With Eugene Levy

Louis Friedman: The point has been made that new technology, specifically, the space shuttle, has made the U.S. Space Act obsolete and the separation of the civilian space program from the military an anachronism. How do you see that?

Eugene Levy: Undeniably, the United States should maintain a military capability that is adequate to protect our security at home and our essential interests abroad. And most people who think clearly about that will, I think, agree. It is important that we perceive ourselves and be perceived by others to have an adequate capability. But beyond that, there are important social and philosophical principles which we adhere to in this country. One of these is that our society is fundamentally a civilian society and that we do not militarize a national activity unless the case is truly compelling. I remember learning in school that in the United States the military is constituted to be and to remain a tool of the civilian society. I believe that this principle is precious and should be preserved.

LF: What are our motivations to study the solar system?

EL: Some of our scientific motivations for solar system exploration are: to gather the clues that will tell us about the origin of the Sun and planets, to learn the history of the planets and thus the laws and processes that govern planetary evolution, to determine how physical laws shape the universe in which we live, and to learn of the conditions that gave rise to the origin of life on Earth and perhaps elsewhere.

LF: How is this related to other areas of science?

EL: There are many close connections; large areas of astronomical science—including study of the planets—achieve their greatest significance and intellectual power when applied together. For example, astronomical studies of the conditions and processes of star formation in the galaxy are tied closely to our growing knowledge of the details of the formation of our own star—the Sun—and its associated system of planets. The generalities of star formation, as revealed by broad astronomical studies, and the details of the solar system's history that can be revealed by spacecraft studies are complementary sets of information, each unique and each essential to our eventual comprehension of the formation of stars and planets.

LF: Do the investigations of the planets have any connections to sciences about the Earth?

EL: Yes, for example the evolution of Earth's surface and interior is a field of scientific inquiry where our deepening comprehension of the planets will be essential. Our thinking about geophysical phenomena is founded upon the recently developed theory of plate tectonics—continental drift and mantle convection. However, the origin of Earth's tectonic behavior is not well understood. Both Venus and Mars are crudely similar to Earth, but seem to have evolved in vastly different tectonic regimes. By learning the details of their evolutionary histories, as well as important facts about their internal constitution, we will be able to synthesize a general understanding of planetary tectonics and so achieve a real grasp of major geophysical phenomena.

In addition, observations of other systems stimulate our ideas and provoke us to examine yet unconsidered possibilities. Studies of Venus' upper atmosphere made us aware of man-made dangers to Earth's protective ozone layer; studies of the surface of Mars stimulate a new appreciation for the possible instability of terrestrial planet environments.

LF: Are there important advances that we could make in investigations of the origin of the solar system?

EL: Yes, this field is ripe with potential for significant advances in knowledge and understanding that can be achieved through spacecraft investigations. There are whole classes of primitive objects in the solar system—comets and asteroids—that have not even been approached by spacecraft. We believe that these small bodies were formed with too little internal energy to fuel the kind of continuing evolution that has obliterated most of the evidence of the primordial character of planetary material; the comets and asteroids are well-preserved remnants of the material from which the planets originally formed. The information that would be obtained through spacecraft investigations of comets and asteroids would make decisive contributions to our grasp of the conditions and processes of solar system formation.

LF: In this connection you have talked only about comets and asteroids. Do the planets have little to offer to these questions?

EL: By no means. Our recent studies of Jupiter and its satellite system reveal that they form a "miniature" solar system. Observation suggests that the formation of the Jovian system proceeded in a manner that is analogous to the formation of the solar system itself. The similarities and differences between this system, the other giant-planet systems, and the solar system as a whole, will certainly guide our thinking about the formation of stars, planets, and satellite families.

LF: You said before that planetary and solar system investigations teach us about physical laws generally in the universe. Can you give me an example?

EL: In recent years we have discovered that large-scale systems of plasma and magnetic fields are common in the universe, and that their dynamical behavior is responsible for a large class of highly energetic astrophysical phenomena. The solar system offers a variety of magnetized plasmas for our investigation. These are the only such systems accessible to us and our spacecraft study; they are therefore crucial to guide our understanding of such objects throughout the universe. These systems include Earth's magnetosphere—energized by the solar wind and perhaps analogous to some extragalactic radio sources—and the magnetosphere of Jupiter—partially energized by that planet's rotation and perhaps partially analogous to pulsars.

PHOTO: JPL/NASA

Two Galilean satellites, Io (left) and Europa (right), transit across Jupiter. This giant planet and its system of four large moons constitute what some scientists have called a "miniature solar system." It could be a convenient place to study the development of the solar system.

LF: You seem to suggest that planetary science is an important part of many scientific activities.

EL: Solar system science deals with those areas of human knowledge that stand between the detailed and specific understanding that is produced by Earth and laboratory sciences and the broad and generalized information that we can gather through remote astronomical studies of distant objects. I believe the unique and essential role that solar system science plays is that of tying together the diverse elements of cosmical science, producing a coherent comprehension of the universe.

LF: Besides expanding scientific knowledge, what other motivations are there for space exploration?

EL: Societies undertake such great works of science and exploration for many reasons beyond the gathering of new knowledge. By taking on great and visible works of technology, in a world where broad technological capability is the most significant source of economic well-being and power, we demonstrate and solidify our position of world leadership. As a nation, we should be involved at the conceptual frontiers of human activity; it stimulates our scientific and technological development.

I expect that human society eventually will expand its economic activity beyond Earth and into extensive regions of the inner solar system. It is uncertain when such activities will become economically important; it would be premature to mount major resource surveys or mining expeditions. However, sustained scientific investigations will, as a matter of course, reveal most of the information needed to assess the resource potential of extraterrestrial bodies, and at a pace sufficient to ensure that the United States will not be left behind in any important developments.

LF: Even if there are a lot of challenges in planetary exploration, some believe it can wait. Why not a hiatus?

EL: A hiatus now would result in a large loss of accumulated expertise and capability. Planetary exploration is not an activity that can be stopped and started in a short time. People cannot be put in a deep freeze and reactivated ten years later as if nothing had happened. We would have to rebuild nearly from scratch.

LF: But can we afford a planetary program now?

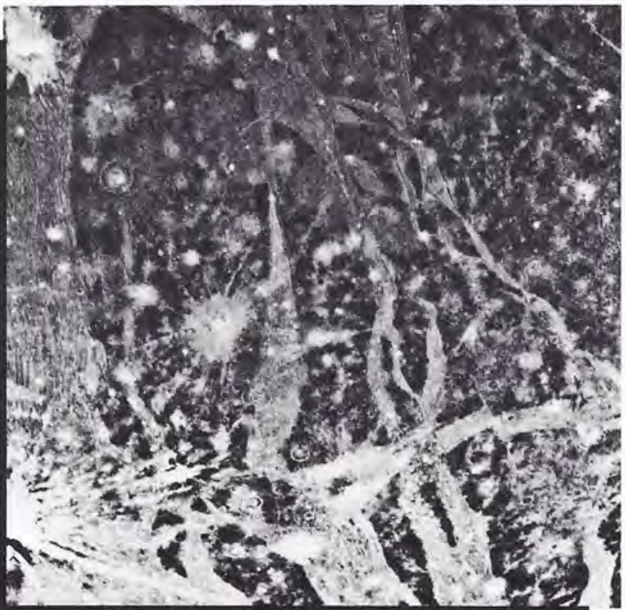
EL: A flexible approach to planetary missions would allow healthy scientific activity that is responsive to budgetary problems. Planetary exploration makes a small demand on national resources. The present financial commitment to the planetary program, in terms of real dollars, is less than 25 percent of what it was around 1973 and 1974. The entire budget of the NASA planetary program is nearly the same as the budget for a typical campus of a moderate size university. Set against the historical significance of the solar system exploration program, this is a small drain on the national wealth. The disturbing implication of statements by administration officials is that we, as a nation, will turn our backs and walk away from this important endeavor. □

Detour Assists

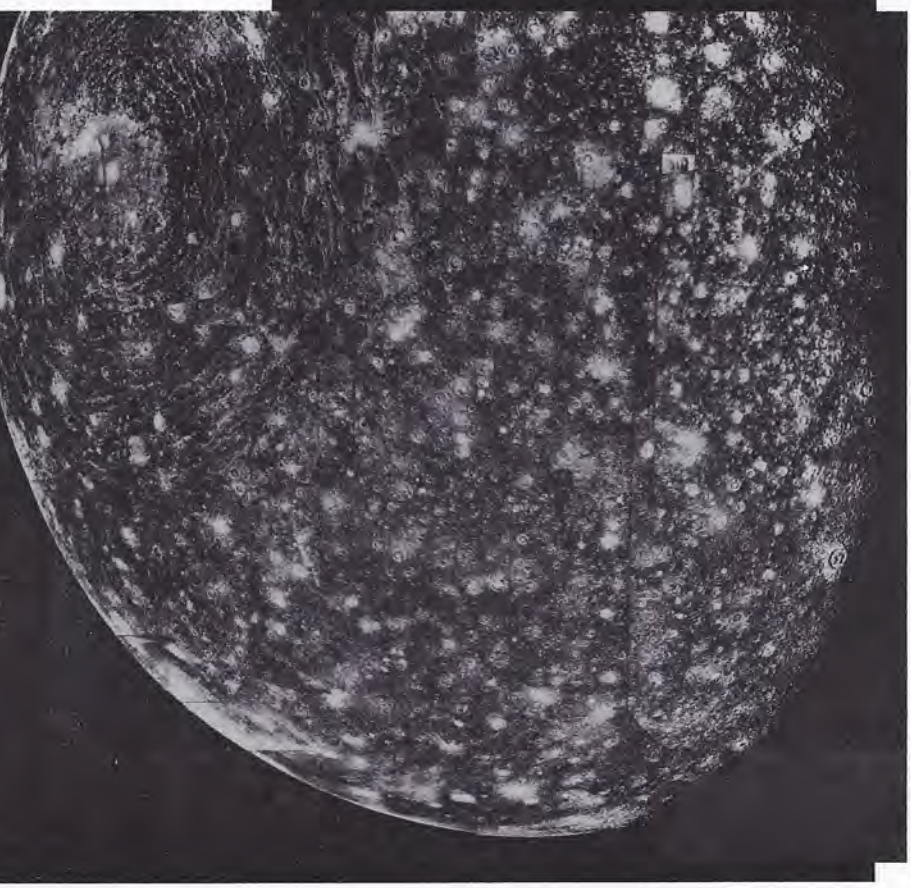
by Louis D. Friedman

A discovery made by Gerry Hollenbeck eight years ago is helping to keep the *Galileo* mission to Jupiter alive. The orbiter and probe mission had been rescued from the budget-cutters several times only to be threatened by delays in the development of the *Centaur* upper stage, the rocket that was to have launched the spacecraft from the space shuttle. Without a powerful booster, how could *Galileo* get to Jupiter?

Gerry Hollenbeck, a trajectory analyst with Martin Marietta Corporation, had the answer. This clever and imaginative celestial mechanician discovered a new class of trajectories called VEGA (Venus Earth Gravity Assist) and ΔVEGA (ΔV Earth Gravity Assist). *Galileo* could follow one of these trajectories and reach Jupiter without a massive boost from a *Centaur*. Using Hollenbeck's discovery and their own resourcefulness, project designers have saved *Galileo* from oblivion and, we hope, from further delay.



***RIGHT:* Bright, rayed impact craters and striations mark the face of Ganymede, Jupiter's largest known satellite. The peculiar linear markings probably resulted from deformation of its icy crust. *BELOW:* Impact craters pockmark the surface of Callisto, one of the large satellites of Jupiter that will be studied by the Galileo orbiter. Scientists believe this surface is one of the oldest in the solar system, remaining basically unchanged for billions of years.**



PHOTOS: JPL/NASA

Galileo will be the most demanding payload ever sent into interplanetary space. The spacecraft has two parts; a 2000-kilogram orbiter carrying nine instruments, and a 335-kilogram atmospheric probe with six instruments. Before reaching Jupiter, the spacecraft will release the probe to penetrate the gaseous giant and radio back to Earth information about the composition, temperature, and pressure of the atmosphere before the probe is crushed in the depths of the planet. After separating from the probe, the orbiter will brake into orbit about Jupiter, and repeatedly swing by the large Galilean satellites, returning images and information on the planet and its moons.

The spacecraft will need a great deal of energy to get from Earth orbit to Jupiter. Even if the powerful *Centaur* could be used, mission planners would still have had to rely on several "tricks" of celestial mechanics to complete *Galileo*'s Jovian tour. These tricks are based on the principle of gravity assist. This principle is a consequence of Newton's laws of motion, but it was not analyzed until 19th century mathematicians studied the orbits of comets. When a comet passes close by one of the giant planets, its trajectory is permanently altered by the gravity of the larger body; it receives a "gravity assist." The short-period comets—those that regularly return to the inner solar system—have been diverted into these short orbits by gravity assist.

With the advent of space flight in the 1950's and 1960's, celestial mechanicians began to look more closely at the concept of gravity assist. Mike Minovitch and Gary Flandro at JPL, D. F. Lawden in England, K. A. Ehricke at General Dynamics, Walt Hollister and Richard Battin at MIT, and G. A. Crocco in Italy were pioneers in the field. They saw that gravity assist was not merely a perturbation to a trajectory that must be considered in calculations, but provides a means of controlling or shaping a trajectory.

The designers of the *Mariner 10* mission were the first to use gravity assist to reach a planet. The spacecraft used gravity assist from Venus to reach Mercury, and used a gravity assist from Mercury to return to the planet. *Pioneer 11* and the *Voyagers* used the principle to reach Saturn after passing Jupiter, and *Voyager 2* will encounter Uranus and Neptune with help from Jupiter and Saturn. *Galileo* will use gravity assist to help it into orbit about Jupiter and to tour among its moons. How does gravity assist work? When a spacecraft on a trajectory about the Sun (flying from one solar system body to another) passes close by a planet or moon, its trajectory is bent by the gravity of that body. If it flies in front of the planet (in the direction the planet is moving), the spacecraft's trajectory is bent back and it loses velocity.

If it flies behind the planet, it gains velocity.

This sounds like getting something for nothing—a violation of the law of conservation of energy. How can the spacecraft pick up speed with no work? In its motion relative to the planet, the spacecraft comes in and leaves with the same speed and the same energy—so there is no violation. But velocity is speed *and* direction, so when the spacecraft changes direction, its velocity relative to the Sun is increased or decreased. The energy of the spacecraft and its trajectory about the Sun are both changed. It has received a gravity assist.

Since the total energy of bodies in orbit around the Sun must be conserved, if a spacecraft gains energy by gravity assist from a planet, the planet must lose energy. Jupiter and Saturn lost some orbital energy when *Voyager* flew by them! Fortunately, the loss was in the ratio of the mass of the spacecraft to the mass of the planet, or about 0.0000000000000000000004 percent. We leave it to future generations to worry about the effects of numerous spacecraft flying by a planet or moon.

The *Galileo* mission depends intrinsically upon the idea of gravity assist. Repeated flybys of the Galilean satellites of Jupiter (Io, Europa, Ganymede and Callisto) are made possible by targeting one encounter so that the satellite perturbs the spacecraft's trajectory to the next encounter. John Beckman of JPL developed this idea into an orbital "tour" of the Jovian system. He coined the term "orbit pumping" to describe the changes in orbital energy resulting from satellite encounters. Then Chauncey Uphoff and Phil Roberts, also of JPL, came up with "orbit cranking," which would use gravity assist to change the orbital plane to allow more tours through the system. Mission designers could also use gravity assist to ease *Galileo* into Jupiter orbit by flying it close by Io and losing energy before braking.

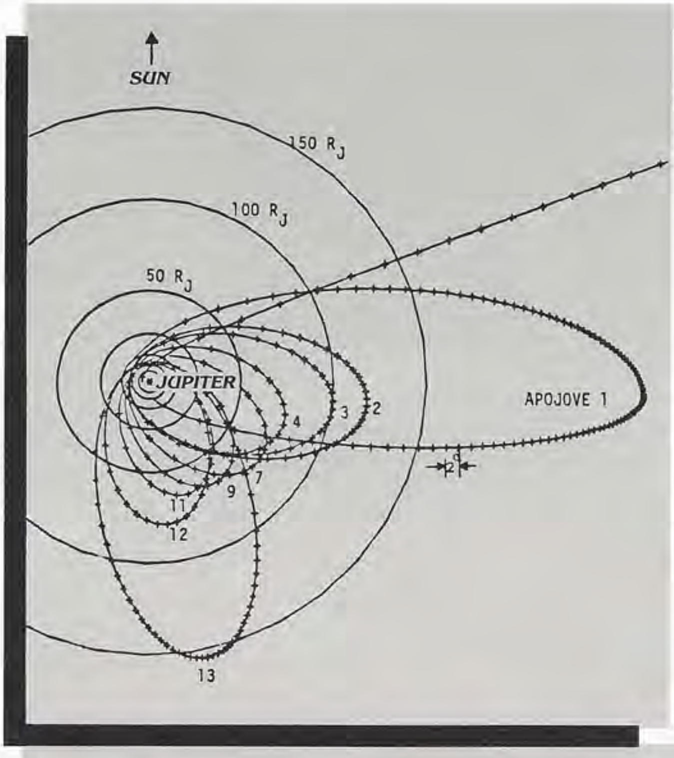
At the same time the JPL scientists were planning an orbital tour around Jupiter, Gerry Hollenbeck took the tour idea and applied it to the entire solar system. By treating Venus and Earth as satellites of the Sun, he found that gravity assist could be used for trajectories between planets.

On a VEGA (Venus Earth Gravity Assist), a spacecraft would first fly by Venus to gain speed, then loop around to the Earth to pick up more speed before heading out to its target planet. The spacecraft could reach the outer planets for the same price, in launch energy, as an ambitious inner planet mission. Hollenbeck also found that if a spacecraft launched from Earth into orbit around the Sun maneuvered in orbit (ΔV for change in velocity) and returned to fly by Earth (EGA for Earth Gravity Assist), it could gain as much energy as on a VEGA trajectory. Hence, ΔVEGA.

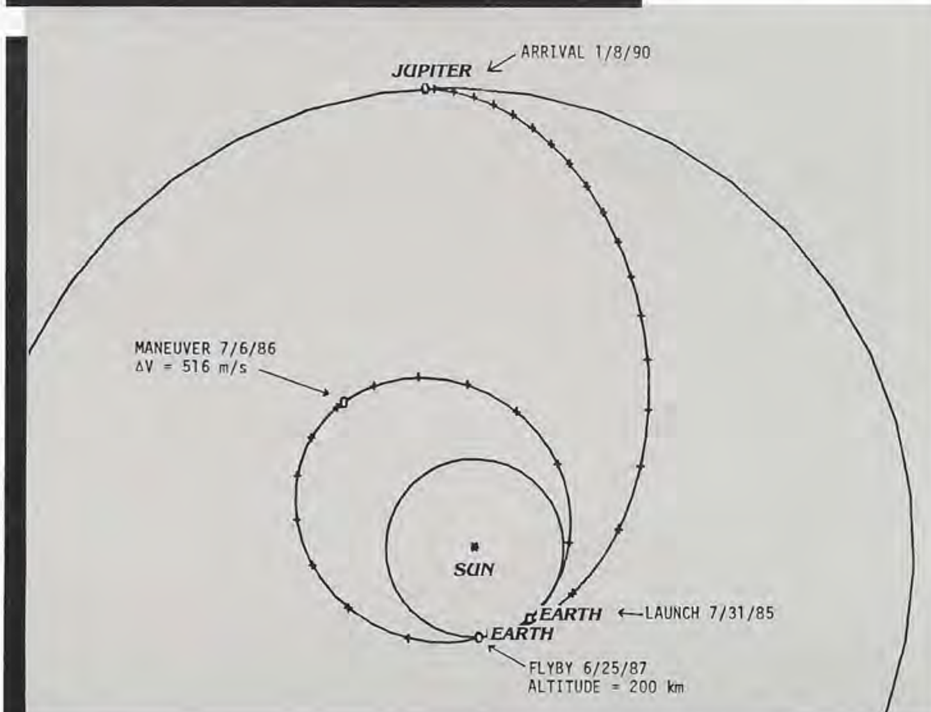
Galileo will probably follow a ΔVEGA trajectory to Jupiter. Mission designers have been able to replace the desired *Centaur* booster with Gerry Hollenbeck's trick of celestial mechanics. The ΔVEGA trajectory will add two years to *Galileo*'s flight time so it will not encounter Jupiter until 1990. But at least it will get there—*Galileo* is the only approved planetary mission for the next decade.

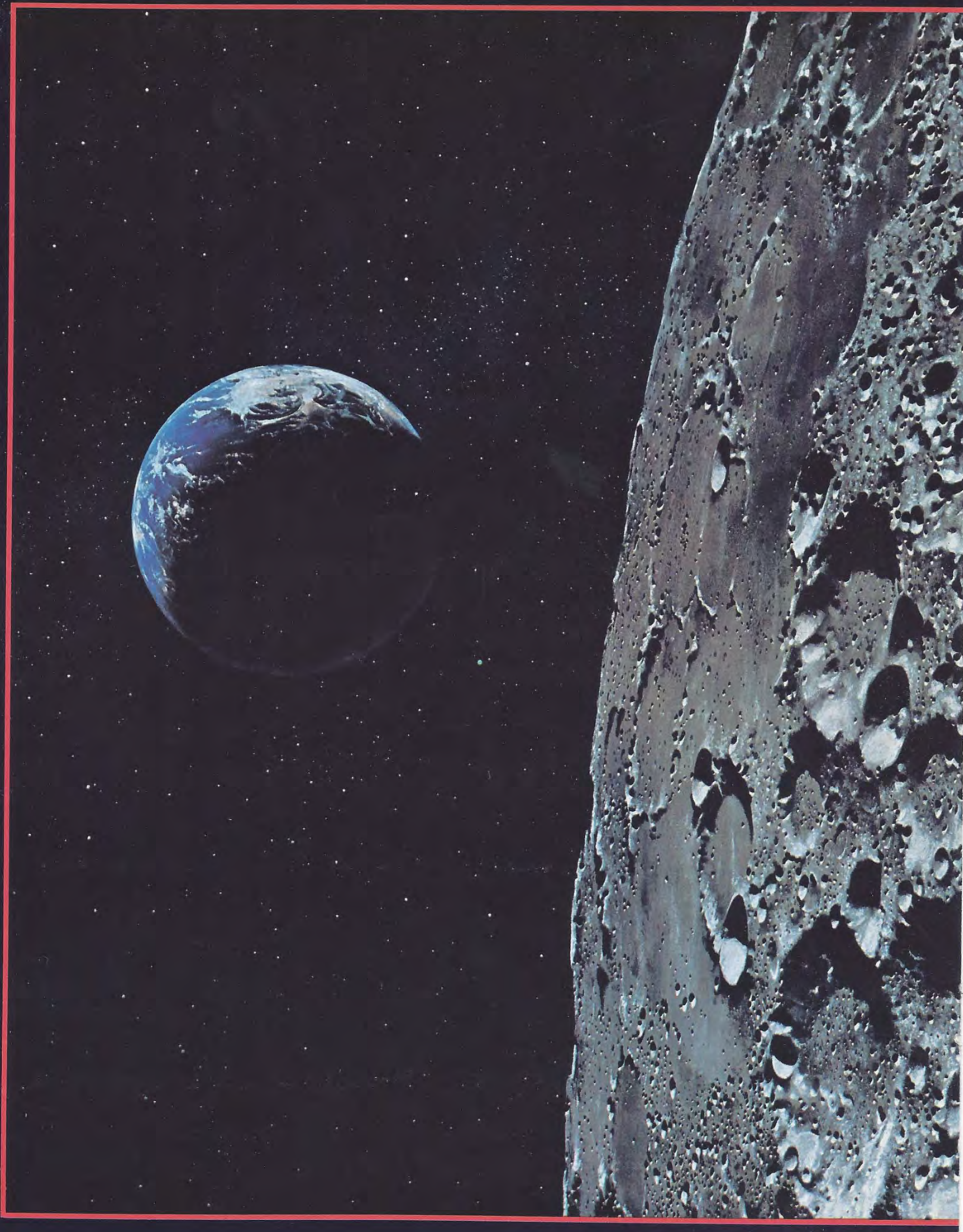
And the two years *Galileo* will spend in the inner solar system on the ΔVEGA trajectory won't exactly be boring—in 1987 the spacecraft will fly by Earth at an altitude of only 200 kilometers, and take one last look at its home planet before heading out to Jupiter.

Planetary Society Executive Director Louis Friedman worked on the design of Galileo *and other advanced planetary missions at JPL.*



LEFT: The path of the Galileo orbiter through the Jovian system. Apojove 1 is the point in the spacecraft's first orbit farthest from Jupiter. The other orbits are numbered consecutively. The orbits of the Galilean satellites are indicated by the four small circles around Jupiter. The larger circles give distance from the planet in radii of Jupiter.
BELOW: A computer print-out of the ΔVEGA trajectory that Galileo will probably follow to Jupiter.

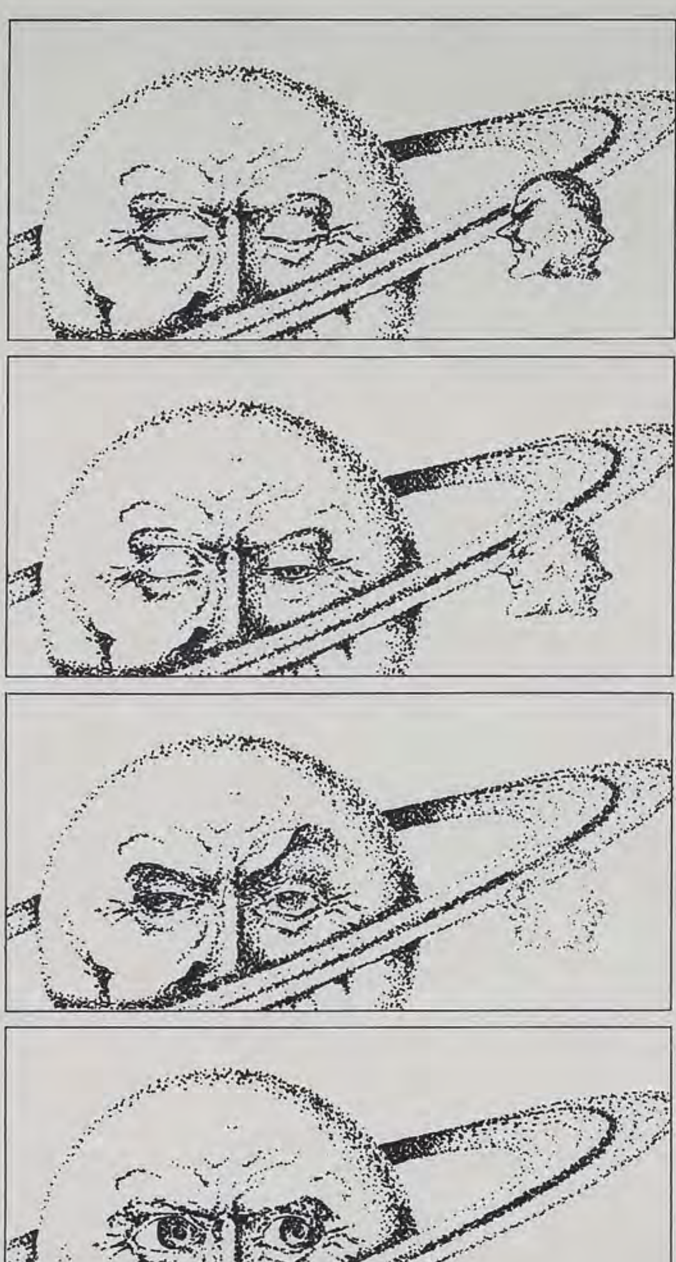




The Earth rises in the sky beyond the Moon, whose silent, scarred surface contrasts sharply with the living, changing face of Earth. Only *Apollo* astronauts have seen such an Earthrise from lunar orbit, and their exclamations of wonder still ring in our ears. In the future, this sight may become commonplace. Yet, in the way of other marvels of nature, it will continue to move us deeply to watch our home planet rise over an alien horizon. And, as Archibald MacLeish wrote, to see it "small and blue and beautiful in that eternal silence where it floats, is to see ourselves as riders on the earth together, brothers on that bright loveliness in the unending night...."

PAINTING BY PAUL HUDSON/QUOTATION FROM *RIDERS ON THE EARTH*, BY ARCHIBALD MACLEISH, HOUGHTON MIFFLIN COMPANY, BOSTON.

Questions & Answers



ILLUSTRATIONS: S. A. SMITH

I HAVE SEEN NO REFERENCE to the Saturn satellite Janus in any of the* Voyager *literature. Did the satellite disappear?
—Kevin Doxstater, Bakersfield, California

MANY ASTRONOMY TEXTBOOKS list a moon called Janus as Saturn's innermost satellite. Janus is said to orbit Saturn at an average radius of 159,000 kilometers every 17 hours, 58 minutes, 0.5 seconds. In 1980 and 1981, scientists using ground-based sources and the *Voyager* spacecraft were unable to find a satellite in this orbit. But their observations do give a clue as to what researchers did see in 1966, when Janus' existence was first proclaimed.

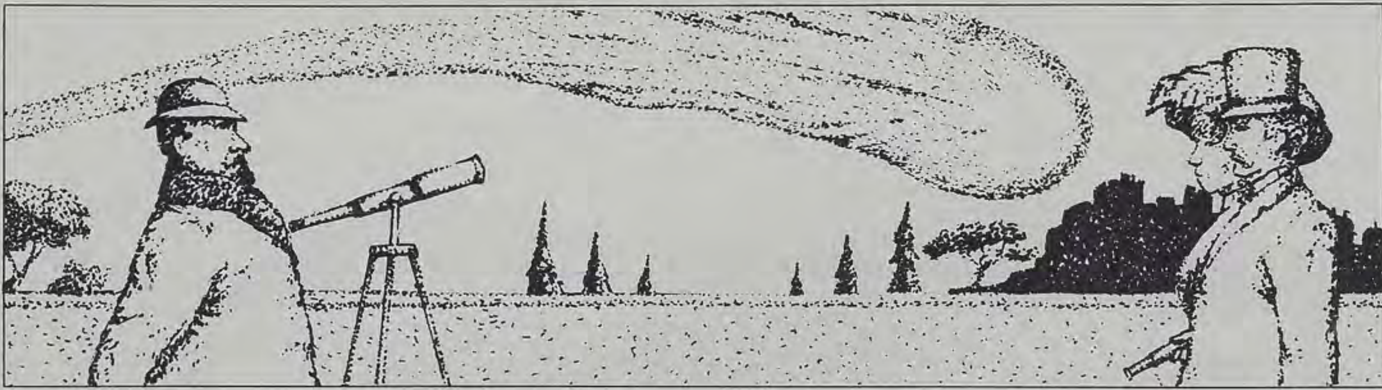
About every 15 years, the Earth passes through the plane of Saturn's rings. At these times, the rings are seen edge on, and become almost invisible. Also, they interfere far less than usual with ground-based efforts to observe faint objects close to Saturn. This alignment occurred in 1966 and was photographed in France and in the United States, at the Lowell and Naval Observatories and at the Universities of Arizona and Texas. At that time, Frenchman Audouin Dollfus announced that he had discovered a new moon—Janus. He provided orbital data measured (incorrectly, it now appears) from only one or a very few photographs.

Several years later, John Fountain and Steve Larson of the University of Arizona evaluated most of the available 1966 American exposures and, in 1978, they reported the discovery of a second inner Saturnian satellite, and gave its orbital period as 16 hours and 40 minutes. In late 1979, *Pioneer 11* flew past Saturn, photographed an object in the Fountain and Larson orbit, and returned data suggesting yet another object in a similar orbit.

In 1980, Earth again passed through Saturn's ring plane, allowing astronomers to apply advanced instruments (including solid-state camera detectors like those to be flown on *Galileo* and the space telescope) to the problem of the inner moons. Several groups obtained excellent data and discovered the first known pair of co-orbital satellites—moons that move in nearly identical orbits. These two satellites have orbital periods of 16 hours, 39 minutes, 50 seconds and 16 hours, 40 minutes, 19 seconds, allowing the inner moon to lap the slower, outer moon every four years.

During their recent flybys of Saturn, *Voyagers 1* and *2* obtained high-resolution photographs of both the co-orbitals. And although the spacecrafts discovered at least eight new moons of Saturn, they found no trace of an object in the orbit reported by Dollfus. He apparently photographed one of the co-orbital satellites, but made large errors in measuring its location.

Will Janus be erased from the texts? This question, like the naming of the eight new moons, will be considered by the International Astronomical Union at its triennial General Assembly, to be held in Greece in August 1982.
—Stewart A. Collins, JPL



WILL HALLEY'S COMET come as close to the Earth in 1986 as it did in 1910? Will it be as spectacular? —Harvey Karns, Oklahoma City, Oklahoma

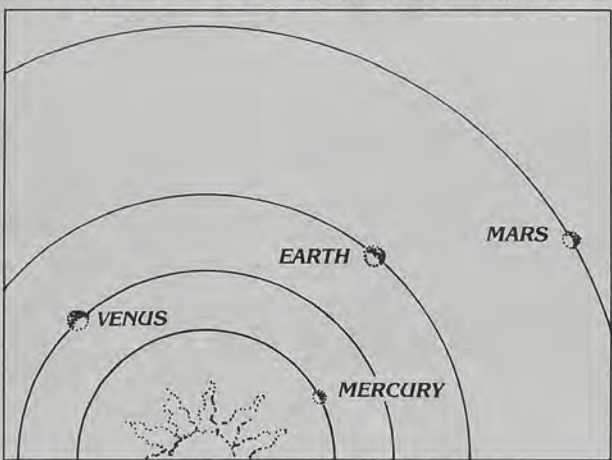
THOSE WHO HAVE BEEN WAITING out the years for a rerun of the spectacular 1910 apparition of Halley's Comet may, unfortunately, be disappointed by its 1986 visit. This time the comet will come within only 63 million kilometers of Earth (on April 11); in 1910 it passed within 23 million kilometers.

On its last visit to the inner solar system, the comet reached perihelion, or closest point to the Sun, while both it and the Earth were on the same side of the Sun. Only when a comet nears its perihelion does it develop the long, streaming tail that can light up the night sky. Halley's Comet will next reach perihelion on February 9, 1986 while it is on the opposite side of the Sun from the Earth, and so it will be impossible to see from our planet when it is at its brightest.

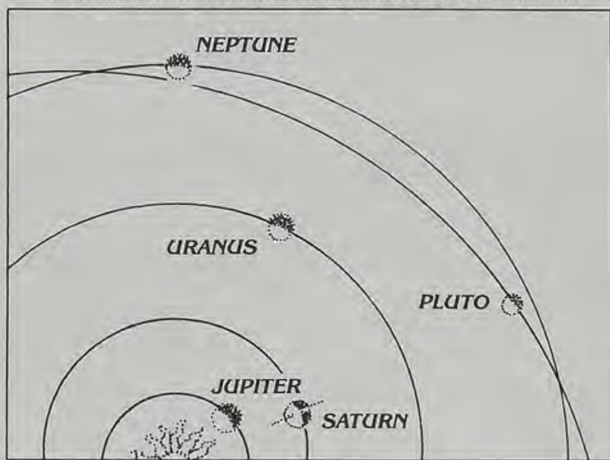
Halley's Comet will be no more than a smudge in the sky to the unaided eye. But for observers who can get away from city light to a dark sky, have binoculars or a telescope, and know where to look, the comet can still be a rewarding sight. It will be best seen after it passes perihelion and approaches Earth in March and early April, 1986.

Halley's Comet will return again in 2061 but, according to Donald Yeomans, a Halley-watcher at JPL, "it won't be any better. That's why we tried to get a space probe...." *–Ed.*

ALIGNMENT OF THE INNER PLANETS ON MAY 15, 1982



ALIGNMENT OF THE OUTER PLANETS ON MAY 15, 1982



IS IT TRUE that the alignment of the planets in 1982 will cause catastrophic earthquakes on Earth? —David Whittall, Tustin, California

DON'T WORRY. While no one can say for certain that the Earth will not experience catastrophic earthquakes in 1982, the prediction made in the book, *The Jupiter Effect,* by John R. Gribbin and Stephen H. Plagemann, is not taken seriously by scientists. And now, the authors themselves disown the prediction.

According to author Gribbin, the original prediction was based on two premises: first, earthquake activity increases when the Sun is more active; second, an alignment of the planets can cause an increase in solar activity. Using these hypotheses, the authors predicted a great earthquake along the San Andreas Fault in California during 1982. But "the fact that the Sun's activity peaked in 1979 proves that the planetary alignments don't affect the Sun's activity. And so the prediction for 1982 falls down," said Gribbin.

Other scientists have pointed out that the authors never had good statistical evidence to support the equation of solar activity with earthquake activity. The 1982 alignment of the planets was also overstated; at their closest, the planets will be spread along an arc of about 135° around the Sun. This much-touted alignment is "more approximate than we made clear," admits Gribbin.

Gribbin published a retraction of the prediction in the June, 1980, *Omni* magazine. But the damage had already been done. Many cranks, cultists and doomsayers have used the book and the authors' positions as scientists to support their own wild theories. The prediction of earthquakes in 1982 has spread among the general public, well beyond those who are familiar with the book. Gribbin insists that he and Plagemann were surprised by the reaction to *The Jupiter Effect.* "We were both young, fresh out of graduate school, and we were a little naive," he said. *—Ed.*

CENTER: An early Arabian compass.
INSET, TOP LEFT: The symbol of Venus (a female lutist) and the sphere of the orbit of the Sun, illustration from the Ajaib al-Makhlukat *of al-Kaswini.*
INSETS, RIGHT: The constellations of Sagittarius and Capricorn, also from the Ajaib al-Makhlukat *of al-Kaswini; design of a water clock showing the spheres of the Sun, the Moon and the zodiac, illustration from the* Automata *of al-Jazari.*

Arabian Astronomy

by Farouk El-Baz

In the Arabian desert, travelers navigate as sailors do at sea. The terrain has long since been robbed of its landmarks by thousands of years of wind erosion. Only vast featureless plains remain, interrupted by seas of dune sand. One sandstorm may change the look of a familiar dune field; the next fierce wind rearranges it again. Because travel was a way of life for the bedouin, these nomads had to know the sky as we know our city streets. To find their way, the Arabians mastered the sky long before history was recorded.

However, astronomy did not develop as a science until the seventh century AD. This development was not limited to the country of Arabia, but extended to all the lands that were conquered by the Muslims, from the Atlantic coasts of Spain and Morocco across central Asia to Malaysia and Indonesia.

Arabian astronomy reached a significant phase with the translations of the ancient Greek philosophers, carried out under Harun Al-Rashid (765–809), the hero of *The Thousand and One Nights.* His father, Al-Mansur, had been impressed by a book from India that dealt with the stars and eclipse predictions. He had the *Brahma-Sphuts-Siddhanta,* or the Opening of the Universe, translated into Arabic and the book remained the standard work on astronomy for half a century. Following his father's example, the new Caliph ordered Ptolemy's *Megiste Syntaxis,* or Great System, translated into Arabic. The resulting work, the *Al-Magest,* became the major source work for Arabian astronomy, and Ptolemy's work was preserved for posterity.

In turn, Harun's son and successor, Al-Mamun (786–833) initiated the next phase. He erected the first observatory of its kind in Baghdad to verify the fundamental elements of Ptolemy's *Al-Magest* and perform additional observations. This encouragement of astronomy came at a time when science was essentially non-existent in Europe. From a practical standpoint, the caliphs wanted to refine the lunar calendar and make better predictions of lunar eclipses and other celestial events. More significantly, the religion of Islam emphasized the study of the vast heavens and the order in the universe as signs of the greatness of God. In one passage, the *Quran,* the holy book of Islam, states: "In the creation of the heavens and of the Earth, and in the succession of the night and day, are marvels and signs for those of understanding heart."

In the Baghdad Observatory, astronomers performed a delicate geodetic measurement of the length of a terrestrial degree. They aimed to determine the size of the Earth. Their results were remarkably accurate: circumference 32,830 kilometers, diameter 10,460 kilometers. Among those who took part in this measurement was Mohamed Al-Khwarizmi (780–850), who also compiled the oldest astronomical tables. After being translated into Latin in 1126, the tables became the basis for other works in both the East and West. Al-Khwarizmi also composed the oldest work on arithmetic and coined the term "algebra." His own name, converted into "algorithm," denotes the system of numerals widely in use today.

Arab caliphs and military commanders often had a flair for astronomy and more than a passing interest in astrology. The naming of Cairo in Egypt is a case in point. On August 8, 969, in the name of Fatimid Caliph, Commander Jawhar Al-Siqilli conquered Al-Fustat, then the capital of Egypt. A Christian born in Sicily, from which his name was derived, Commander Al-Siqilli chose a site northeast of Al-Fustat for a city for the Caliph. He asked his astronomers to look for a sign from heaven to begin building the city walls. It is said that a raven descended at the moment the planet Mars (Al-Qahir, or the Conqueror) reached its zenith. Thus, the city was named Al-Qahira after the feminine version of the planet's name. It came to the West as "Caire," then "Cairo."

Perhaps the most significant feature of astronomy during the golden age of Islam was its accuracy. Muslim astronomers took Greek inventions and elaborated upon them. For example, the astrolabe was invented by the Greeks, but was perfected and became widely used under Islam. The astrolabe is a flat disk with its circumference divided into degrees and a pointer pivoted at the center. If it is suspended by a ring at the top with the pointer aimed at a star, the pointer forms an angle with the horizontal line on the astrolabe. By measuring the angle, astronomers and navigators could determine the height of the star above the horizon. Coupling a single observation with one or more star maps, the user could easily compute latitude, time and direction. The astrolabe, as developed by the Arabs, became the pocket watch, compass and slide rule of the world.

Even under the rule of the Mongols, Islamic astronomy flourished. After Hulagu Khan, a grandson of Genghis Khan, captured Baghdad in 1258, its observatory was destroyed. However, Hulagu's advisor, Nasir Al-Din Al-Tusi (1201–1272), was an outstanding astronomer and he convinced his master to erect an observatory, with remarkably accurate instruments, at Maragha in northwestern Persia (Iran). Hulagu was initially skeptical of spending money for the construction of the observatory. Al-Tusi is said to have told him, "Suppose the Khan ordered someone to drop a large object from a high place. It would produce a very loud noise and frighten everyone. Only the Khan and the person carrying out the order would remain calm, for only they would know what was going to happen." Similarly, only someone familiar with the motion of the stars could make valid astronomical predictions. Al-Tusi was a successful lobbyist. His technique was not unlike that of successful spokesmen for today's space program.

The most important observatory of Islam was founded in Samarkand by Ulugh Beg (1394–1449), grandson of the savage conqueror Tamerlane. The Samarkand Observatory housed a giant quadrant that was used to compile a star catalog. The positions of the stars were noted with unusual

(continued on next page)

PHOTOS: Compass by Steve Tuttle; book pages courtesy the Freer Gallery of Art, Smithsonian Institution, Washington, D.C.

The ancient Greek astronomer Ptolemy constructed a number of devices to explain the apparent motion of the planets through the sky. In a simple model, a planet rode on a epicycle riding on a deferent—a larger circle which rotated about the Earth. This model could not adequately describe the planetary phenomena, so Ptolemy developed the equant point (Figure 1). In this model, C is the center of the deferent, with the Earth and the equant lying at equal distances from C. The center of the epicycle (F) would travel between 1 and 2, and 3 and 4 in equal times. To do this, it would have to vary its speed as it moved around the deferent.

This violated the principle of uniform circular motion, on which the Greeks had based their cosmology. To save this principle, the astronomers at Maragha developed an alternative model (Figure 2). In their system, the planet rides on an epicycle riding an epicycle around the deferent. The apparent motion of the planet is the same as with an equant, but all the circles rotate with uniform circular motion, preserving the philosophic principle.

Two hundred years later, Copernicus was also bothered by Ptolemy's equant point. In his Commentariolus, *the Polish astronomer presented new constructions of planetary motion that are remarkably similar to those developed at Maragha. Some scholars have speculated that Copernicus may have been influenced by the work of the Arabic astronomers.*

FIGURE 1

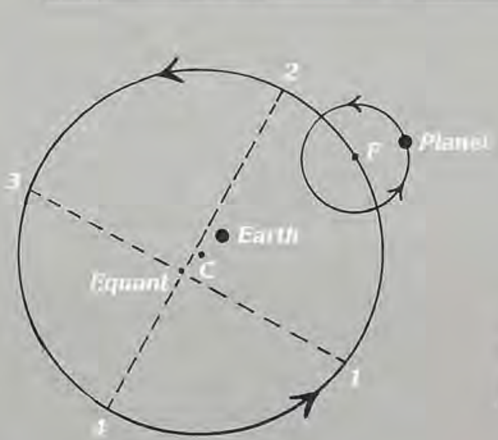
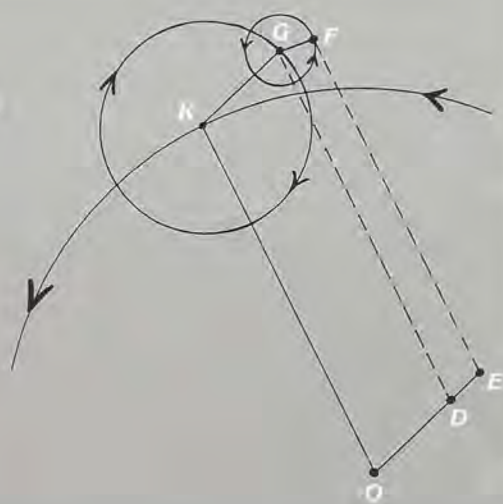


FIGURE 2



precision; their locations were recorded in minutes as well as degrees of arc. Unfortunately, the work at the observatory declined with the death of its founder.

Arabian astronomers placed significant emphasis on planetary theory. Through descriptions by Aristotle, the Arabs knew, but largely ignored, the homocentric model of Eudoxus. In this model, each planet was associated with a nest of spheres that rotated about the center of the universe (the Earth). The system required celestial bodies to rotate in perfect circles with constant speed, and that there should be only one center for all the motions of the heavenly bodies.

The Ptolemaic planetary theory, which was favored by most professional astronomers in medieval Islam, subscribed to the principle of uniform circular motions for celestial bodies, but admitted eccentric and epicycle motions. Ibn Al-Haytham (Ca. 1039) was the first to question Ptolemy's models as presented in *Al-Magest.* He focused his criticism on the concept of the equant. Ptolemy had stipulated that a planet's epicycle moved uniformly with respect to an equant point, rather than an eccentric center. Ibn Al-Haytham correctly deduced that this would mean that the eccentric sphere carrying the epicycle was itself moving with non-uniform velocity, violating the principle accepted by Ptolemy and other astronomers. He concluded that the model was false and must be replaced.

Although Ibn Al-Haytham did not provide an alternate model, his incisive objections may have inspired the important reform of planetary astronomy that was initiated two centuries later by Al-Tusi and his colleagues at Maragha. The departure from Ptolemy was also given impetus by scholars in Arab-controlled Spain, such as the Muslim philosophers Ibn Tufayl and Ibn Rushd, and the Jewish philosopher Maimonides. All three had rejected the Ptolemaic system and demanded a theory that was more in agreement with Aristotelian principles.

The Arabian astonomers successfully produced planetary models that did not violate accepted astronomical principles. These models represented the apparent motion of a planet as the result of a combination of motions, each uniform with respect to its own center. Such models may be prototypes to those of Copernicus.

It is perhaps ironic that a passage of a comet signaled the fatal blow to Arabian astronomy. The Istanbul Observatory was built by Taqi Al-Din, a judge from Egypt who studied with the Jewish astronomer David the Mathematician, and was completed in 1577. That same year a comet appeared. Taqi Al-Din used the occasion to predict the victory of the Turkish army over Persia, and other good fortunes for his patron Sultan Murad III. Although the Turks defeated the Persians, they suffered great losses and a plague claimed many lives. Religious leaders convinced the Sultan that prying into the secrets of the heavens brought about the evil, and so a wrecking crew demolished the observatory only three years after it was built.

As history teaches us, the sciences as well as the arts do not develop in a vacuum. The ability of human beings to excel in their search for answers depends largely on favorable circumstances in the surrounding society. As the civilization of Islam declined, so did the arts and sciences. Fortunately, as Arabian astronomy waned, interest in astronomy began to rise in the West, and the Europeans took up the quest for understanding our universe.

Farouk El-Baz is Director of the Smithsonian Institution's Center for Earth and Planetary Studies at the National Air and Space Museum. He also served as science advisor to the late President Anwar Sadat of Egypt.

News & Reviews

by Clark R. Chapman

The *exploratory* nature of our deep-space missions is a special attribute of NASA's planetary program that has captured the imagination of people worldwide. We follow in the footsteps of Columbus, John Wesley Powell, and the polar explorers of eighty years ago as our spacecraft venture toward uncharted worlds. Yet the glamour of the endeavor also threatens to undo it. *Voyager 2*'s spectacular pictures of Saturn have been dismissed as "show-biz" stuff by powerful government science advisors. They say that "fundamental" insight may not be gained by studying planets. They don't know that beauty is often *not* skin-deep.

Planetary scientists are besieged by the press and popular magazines for accounts of recent flybys. The more searching results of years of analysis take second priority. Not a penny of extra funds has been specifically appropriated for the months and years needed for proper analysis of the invaluable Saturn data.

John Wesley Powell, on returning from his discovery of the Grand Canyon and the Pueblo Indians, was also besieged for popular accounts. Indeed, Powell wrote that while he was testifying before Congress in 1874 on behalf of funds for continued scientific studies of the data, he was informed that his scientific work "would be continued by additional appropriations only upon my promise that I would publish an account of the exploration" and his party's harrowing adventures. Powell wrote his account, but then he got his funds, and America ultimately became a richer country for it. Now planetary exploration is criticized because of its popular appeal, and—incredibly—the program is under the knife.

It is appropriate, indeed, for explorers to describe for the public the obvious "discoveries" of new, not-yet-understood phenomena and to publish pretty pictures—whether of newly found Antarctic penguins, of Pueblo Indian snake-dances, or of the rippling divisions in Saturn's expansive rings. Such accounts cannot and should not delve into the arcane, technical details from which "fundamental" understanding ultimately emerges. But if well-written, such accounts can highlight profound observations and insights in a manner that can be appreciated by any intelligent reader. This month I will mention several good "instant science" articles about *Voyager*'s Saturn flybys, available in popular science magazines.

Chaos on Jupiter and Saturn?

Writing nearly a year after *Voyager 1*'s encounter with Saturn, Caltech scientist Andrew Ingersoll has treated readers of *Natural History* (September, 1981) to a succinct introduction to the planet, its rings and its moons. The article is at once elementary and full of insight. He compares Saturn with Jupiter, and Titan with our similar but more habitable planet, Earth. While Ingersoll pays homage to the beauty of the pictures adjacent to his article, many of his words deal with the invisible deep interior of Saturn and with hypothetical happenings of long ago, when the Saturn system was being formed.

To delve deeper into these mysteries, *Planetary Report* readers should turn to Ingersoll's longer but still lucid comparison of Jupiter and Saturn in the December, 1981, *Scientific American*. He leads readers from the familiar and intricately beautiful *Voyager* movies of Jupiter's Red Spot through several years of analysis by him and his colleagues toward a deeper understanding of how the atmospheres of the giant planets work. Originally, Ingersoll writes, he thought the Red Spot movies showed sheer "chaos." But more scrunity and measurements have revealed "order in the chaos." And some progress has been made in understanding that order and in relating it to the wind patterns on our own planet. Surprisingly, many scientists now believe that the supposedly superficial churnings of the atmospheres of Jupiter and Saturn actually respond to—indeed, are caused by—the deep internal structures of those huge planets.

Ingersoll conjures up fascinating images of Jupiter and Saturn. Jupiter is largely a ball of liquid metal! Deep within Saturn, there is a storm of helium "rain." Jupiter's atmospheric sulfur may come from one of its moons! Essential to Ingersoll's story are the abstractions of quantum mechanics describing the behavior of material at the giant planets' internal pressures, which exceed three million bars; also, the anti-intuitive physics of "negative viscosity," which governs the behavior of atmospheric eddies on Jupiter—and here on Earth! Finally, Ingersoll says if you want to know the sizes of the metallic hydrogen cores hidden deep within Jupiter and Saturn, all that may be required is to compare the winds in the northern and southern hemispheres of each planet: for that purpose, Ingersoll and his associates have been measuring the motions of atmospheric "spots" on those terribly "superficial" *Voyager* pictures of the giant planets.

Fundamental Geology

Most of the pictorial spectaculars acquired during two decades of planetary exploration are of surfaces, not atmospheres. From the Lunar Orbiter's "picture of the century" of the crater Copernicus, through the *Apollo* astronauts' movies taken from the lunar rovers, to the mind-boggling planetary portraits of *Viking* and *Voyager*, pictures have constituted most of the raw data for planetary geologists. Because much geological research synthesizes pictorial data in order to grapple with processes too complex to be treated by mathematical physics, geology has been unfairly labeled by some as superficial.

The latest objects of geological scrutiny are Saturn's satellites, and the surface of each one (except Titan) is described by Laurence Soderblom and Torrence Johnson in the January, 1982, *Scientific American*. Given research funds, the fundamental geological analysis of these ice-rock bodies will be done over the coming years. Also, we have glimpsed the surface of Venus, thanks to the small radar flown on the *Pioneer* Venus orbiter. Global comparisons of the topography of Venus and Earth are yielding a planetary context in which to evaluate modern views of our own planet's geology. You can read about these promising beginnings in an article by James Head, Sandra Yuter, and Sean Solomon (*American Scientist*, November/December, 1981).

Clark R. Chapman does research in planetary astronomy, geology, and geophysics at the Planetary Science Institute in Tucson, Arizona, a division of Science Applications, Inc.

WASHINGTON WATCH

by Louis D. Friedman

Contrary to earlier rumors, the budget President Reagan sent to Congress for fiscal year 1983 finally does include funding to continue not only the operation of *Voyager* and the Deep Space Network, but also to develop the *Galileo* mission for its planned 1985 launch to Jupiter. However, the *Centaur* upper stage which was to launch *Galileo* from the shuttle was cancelled and the *Galileo* mission now has to be altered with some reduction in capability and with a substantially delayed arrival at Jupiter (see article on page 6). The Venus Orbiting Imaging Radar (VOIR) was cancelled—a serious blow to future U.S. space efforts. There are now *no* deep space missions in the NASA plan except *Galileo*. Society Vice-President Bruce Murray discusses the implications of this outcome to future planetary exploration in his editorial on page 3.

Somewhat paradoxically, NASA was the only agency, other than the Department of Defense, whose overall budget was increased in the Reagan proposal. However, all of the increase is earmarked for shuttle development and operations—largely justified on national security grounds.

Congress is now turning its attention to these topics as it considers President Reagan's budget for fiscal year 1983. The House and Senate Budget Committees are already at work. They will set overall limits for appropriations to the various functions of the federal government. Although there has been no intrinsic opposition voiced, the NASA budget could be a target since it is a "discretionary" item. The Authorization Committees (the House Science and Technology Committee and the Senate Committee on Commerce, Science and Transportation), who review and authorize specific projects, will give more substantial consideration to the future of U.S. space exploration. Along with the Appropriations Committees, they will consider the NASA budget item by item over the next few months.

Many members have asked us how to express support for continued U.S. exploration of the solar system. Although not immediately effective, letters to Congress can show general popular interest. Writing to your own Congressman and Senators with views on issues like *Galileo,* the Search for Extraterrestrial Intelligence, general support for scientific research and the future of planetary exploration is an expression of every citizen's right to be heard—among many other voices on many topics. Communications to the Congressional committees involved can also be important. If your own Congressman or Senators are on these committees, your letter can be doubly effective. Besides Congress, other public officials who receive letters on the space program are: President Reagan, the White House, Washington, D.C. 20500; Science Advisor Dr. George Keyworth, the Office of Science and Technology Policy, Washington, D.C. 20500; and NASA Administrator Dr. James Beggs, NASA, Washington, D.C. 20546.

Louis Friedman, Executive Director of The Planetary Society, spent one year as a Congressional Fellow with the Senate Committee on Commerce, Science and Transportation.

Society Notes

The Planetary Society is pleased to announce that, by special arrangement with the American Institute of Aeronautics and Astronautics, members of The Planetary Society will be admitted to two special sessions and the exhibits of the AIAA annual meeting in Baltimore on May 25, 1982. The first session, to be chaired by the Society's Executive Director, Louis Friedman, is entitled "Humankind in the Solar System: Exploration and Expansion." This afternoon session will include six presentations on the possibilities of future exploration of the solar system. The second session, "Of Science Fiction Futures," will be held that evening. Ben Bova, editor of *Omni* magazine, will chair this event featuring major science fiction writers discussing their ideas on the future of space exploration.

Both sessions and the technical display exhibits will be held at the Baltimore Convention Center in Baltimore, Maryland. Planetary Society members will be admitted to these sessions and exhibits at a special admission rate of $5 per person. This is in lieu of the usual $20 registration fee required by the AIAA for one-day attendance at the meeting. Planetary Society members must present their membership cards when purchasing their tickets to take advantage of this reduced admission charge.

Members of the Congressional Committees that oversee planetary exploration are listed on this page.

They may be written at:
U.S. Senate, Washington, D.C.;
U.S. House of Representatives, Washington, D.C. 20515.

Committees of the Senate

COMMERCE, SCIENCE, AND TRANSPORTATION
(Suite 5202, phone 224-5115, meets first and third Tuesdays of each month)

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Barry Goldwater, of Arizona
Harrison H. Schmitt, of New Mexico
John C. Danforth, of Missouri
Nancy Landon Kassebaum, of Kansas
Larry Pressler, of South Dakota
Slade Gorton, of Washington
Ted Stevens, of Alaska
Bob Kasten, of Wisconsin
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Ernest F. Hollings, of South Carolina
Daniel K. Inouye, of Hawaii
Wendell H. Ford, of Kentucky
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J. James Exon, of Nebraska
Howell Heflin, of Alabama

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Daniel Patrick Moynihan, of New York
J. James Exon, of Nebraska

Underlined names are the Chairmen and Ranking Minority persons of the subcommittees concerned with the space program.

Names in italic type are Republicans; names in roman are Democrats.

Committees of the House

SCIENCE AND TECHNOLOGY
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James H. Scheuer, of New York
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A Talk with Hans Mark

(continued from page 5)

for one man's benefit is another man's poison. All I know is that applications and scientific research go together very closely.

I'll argue that the remarkable things done by J. J. Thomson, the discoverer of the electron, and others in the early years of atomic physics were possible because, for the first time, they could make vacuum pumps with electric motors that worked well. A rather mundane technology drove this enormous intellectual development, just the way the ICBM drove the development of planetary exploration.

LF: Do you feel we must couple scientific exploration with military developments?

HM: Yes, and I feel very confident of that. We couldn't have justified the shuttle on space exploration alone—it had to become a national launch vehicle, it had to be something everyone could use. We didn't put *Apollo* on the Moon to pick up rocks, we put *Apollo* on the Moon to beat the Russians. It was a question of national prestige and national policy, but we got a hell of a lot of good science out of it. *Apollo* is a classic example of that tradition.

LF: Part of the rationale behind The Planetary Society is that, while science alone cannot justify $500 million missions, the extraordinary public interest in space exploration could.

HM: I'm not sure that's enough.

LF: I believe planetary exploration is the sort of thing people want their government to do, and they don't need the militaristic or nationalistic argument.

HM: I disagree with that. It has to be sustained by some overriding national imperative. The shuttle was not supported by popular interest; it was supported by a national security imperative.

LF: I agree with you on the politics as they were. I'm just saying that the popular support of exploration demonstrated by The Planetary Society....

HM: I don't think you're right; that's really a mistake. It's never happened in human history, as far as I know. The kind of exploration that interests you and me is always done by a very small number of people who, because a society is successful, have the luxury to do things that are *not* socially imperative. Out of that, enormously important consequences have always followed. But you can't predict them. Therefore, people won't pay for exploration on the basis of what might be accomplished. You've always got to find some other reason.

LF: We'll quote this discussion in *The Planetary Report* and I hope we provoke some comment.

HM: Look, I'm a very strong supporter of The Planetary Society, I'm a charter member. I was on the Board of Advisors, and I'm personally very committed to the idea of planetary exploration. I'm just trying to tell you what I believe to be the political facts of life. I know my friends in the planetary business don't like me because of that. □

Two important new books are offered by The Planetary Society:

The Grand Tour: A Traveler's Guide to the Solar System, by Ron Miller and William K. Hartmann, takes its readers on a profusely illustrated tour of worlds in our solar system. The tour's itinerary is based on the size of each world visited, beginning with massive Jupiter and ending with the tiny Martian moon Deimos, the asteroids and comets. Over 80 original paintings by the authors are supplemented with photographs taken by unmanned probes and *Apollo* and *Skylab* astronauts, and with relief maps of many of the planets and their moons. A glossary of terms and a statistical chart with data on the discovery, diameter, orbital period, gravity, surface material and atmosphere of each world on the tour gives the traveler a helpful reference guide.

The Surface of Mars, by Michael H. Carr, summarizes the results of the five-year *Viking* mission to Mars that returned an enormous amount of new information about the red planet, with its surprisingly diverse geology and evolutionary history. According to Carr, leader of the *Viking* Orbiter Imaging Team, "The facts about Mars turned out to be almost as bizarre as the fiction." Several recent maps of the planet, charts, diagrams and over 150 *Viking* pictures illustrate the text. Retail price of *The Surface of Mars* is $45, but the book is available to Planetary Society members at a special price of $20. Copies are limited.

Keep the Spirit of Planetfest '81 Alive! Order Your Souvenirs Now!

Posters, programs, T-shirts and other keepsakes especially produced for Planetfest '81, the Pasadena Planetary Festival commemorating *Voyager 2's* encounter with Saturn, are available to all Planetary Society members.

Two beautiful color posters were designed for Planetfest '81 by students from Art Center College of Design in Pasadena. The horizontal poster is the famous photograph taken by *Voyager 1* as it departed the Saturn system. Highlights of *Voyager 2's* encounter with Saturn are listed across the bottom. The vertical poster displays Saturn's braided F-Ring—one of the most exciting discoveries of *Voyager 1.* Milestones in planetary exploration are printed at the F-ring's left, providing a timeless reference. The posters are a complementary pair, suitable for framing.

A 24-page program describing Planetfest '81 events is heavily supplemented by summaries of what we have learned about our solar system thus far, and a centerfold illustrates a tour of the planets with full color photos and paintings. The program's informative value far surpasses its use as a listing of events. White T-shirts with the Planetfest '81 logo on the front in brilliant blue and red are cherished by those who own them. Tote bags for books, needlepoint or *The Planetary Report* carry the same bright Planetfest '81 logo on natural canvas. Buttons are available in several styles: Planetfest '81 logo, *Voyager 1* and *Voyager 2* at Jupiter.

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David Hardy is one of Britain's leading space artists. He is also "very keen on photography" and will be combining this interest with his future art work. Atlas of the Solar System, a book of Mr. Hardy's paintings, has just been published by World's Work, Ltd.

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